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To cite this article: P A Savin *et al* 2019 *J. Phys.: Conf. Ser.* **1389** 012122

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Negative anisotropy in Fe₁₀Ni₉₀ films

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Abstract. It is shown that in the Fe₁₀Ni₉₀ film the easy magnetization axis can be formed not along the deposition field, as it occurs in the Fe₁₉Ni₈₁ film, but across, that is a “negative anisotropy” effect occurs. A model that qualitatively describes this effect is proposed. Using the Kerr magnetometer, local measurements of the variation of the direction of the easy magnetization axis over the area of the film sample Fe₁₀Ni₉₀ were carried out and compared with the general view of the domain structure.

1. Introduction

Iron-nickel films are widely used in applications such as magnetoresistive sensors for example [1].

Usually, non-magnetostriction composition Fe₁₉Ni₈₁ films with low coercive force are used. Fe₁₀Ni₉₀ films have not only a slightly greater coercive force, but also a greater magnetoresistive effect and, in addition, they can exhibit an interesting physical effect of “negative anisotropy”.

For the controlled formation of an easy axis during film deposition, a deposition field (H_{dep}) is applied usually in the substrate plane, and an easy axis is formed along this direction [2].

On the film Fe₁₀Ni₉₀ we observed the formation of the easy magnetization axis perpendicular to the deposition field, and not along, as in the case of Fe₁₉Ni₈₁.

In general, uniaxial anisotropy can be described by a free energy density

$$E_k = K_{\pm} \sin^2(\varphi) \quad (1)$$

where φ is angle between \mathbf{M} and \mathbf{H}_{dep} and either $K_{+} > 0$ or $K_{-} < 0$ is chosen, depending on whether the easy axis is parallel or perpendicular to the deposition field.

Therefore, typical permalloy films have positive anisotropy, since the easy axis is formed along the deposition field.

Earlier it was reported about the existence of a similar phenomenon, but it was about small regions of the film and the question of the origin of the effect remained open [3].

Here we want to offer a model for the qualitative description of this phenomenon.

2. Model

The fact of the formation of this anisotropy can be explained by the joint action of two factors: anisotropic distribution (migration) of defects and magnetostriction with stresses.

The anisotropy mechanism is explained by the scheme (figure 1). The deposited film can be represented as a set of individual crystallites (squares) and defects (dots). At an elevated temperature



(accompanying the deposition process), randomly distributed defects can migrate to the grain boundaries. The presence of the technological field (H_{dep}), removes the degeneration of the migration directions, reducing the magnetostatic energy [4]. As a result, along the direction of the deposition field, "chains" of crystallites are formed, separated by clusters of defects.

Now, in order to create an easy magnetization axis perpendicular to the deposition field H_{dep} , it is necessary to apply a tensile stress along the "chains", since $\text{Fe}_{10}\text{Ni}_{90}$ has a negative magnetostriction [5]. This is provided by the following mechanism.

The coefficient of thermal expansion of the metal film is much larger than that of the glass substrate. As a result, upon completion of the deposition process, the film undergoes tensile stresses. These stresses act both along and across the "chains" of crystallites. However, the anisotropic distribution of defects damps the stresses in the transverse direction, and the resultant is the longitudinal tension of the "chains" is dominant.

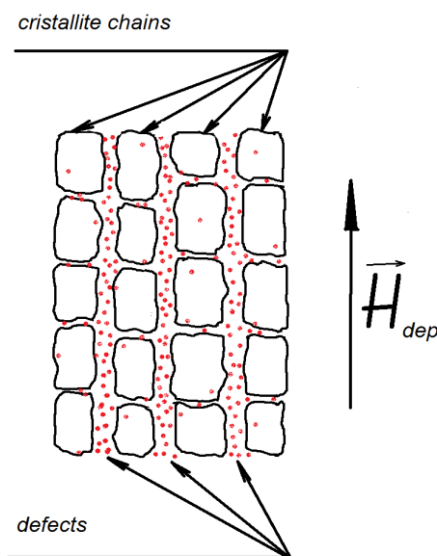


Figure 1. Scheme of formation of "crystallite chains" due to anisotropic migration of the defects.

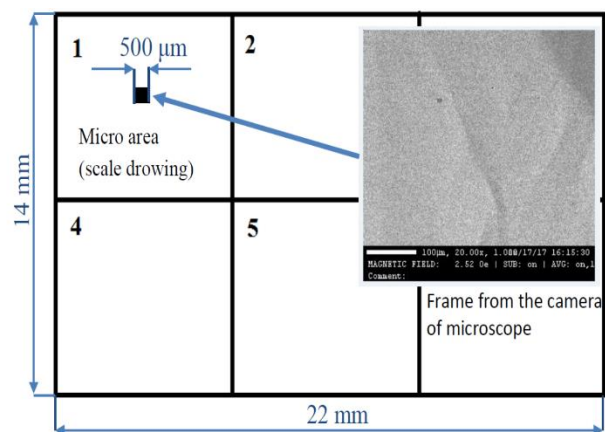


Figure 2. The layout of the studied micro areas.

3. Samples and methods

Magnetic films were obtained by magnetron sputtering of $\text{Fe}_{19}\text{Ni}_{81}$ and $\text{Fe}_{10}\text{Ni}_{90}$ alloy targets on glass substrates with squared shape of 22×22 mm in the presence of a technological magnetic field H_{dep} of 250 Oe, parallel to the substrate plane. The preliminary vacuum in the working chamber was 5×10^{-7} Torr. The deposition of the films carried out at an argon pressure of 1.6×10^{-3} Torr. The thickness of the films was 40 nm. To study the properties of the films, a Kerr magnetometer Evico magnetics was used.

In the $\text{Fe}_{10}\text{Ni}_{90}$ films, we were interested in the distribution of magnetic characteristics over the sample area (22×14 mm). Therefore, we used two observation modes: micro and macro. The size of the micro areas was $500 \mu\text{m} \times 500 \mu\text{m}$ and the macro area was $22 \text{ mm} \times 14 \text{ mm}$ (sample size). The layout of the studied micro areas is shown in figure 2. As you can see, they are located in the centers of the six squares into which the sample is conventionally divided.

4. Result and discussion

The figure 3 shows the magneto-optical hysteresis loops, taken along the direction of the action of the technological field H_{dep} for films of different compositions. From the shape of the hysteresis loops and

the orientation of the domain structure, we concluded that the easy magnetization axis formed either along the deposition field or perpendicular one, depending on the film composition.

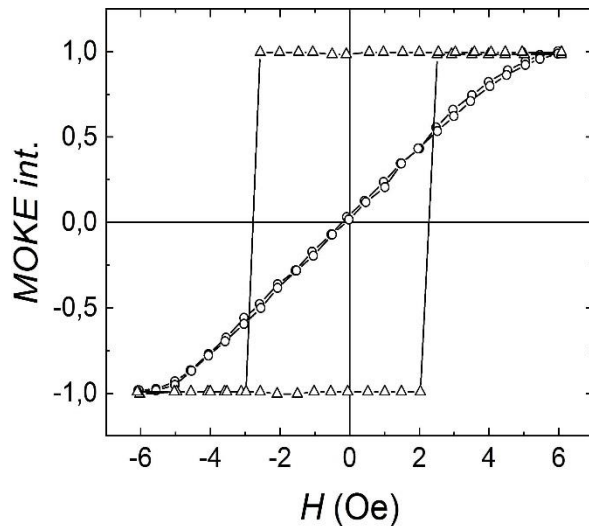


Figure 3. Hysteresis loops measured along the direction of the deposition magnetic field for films of different composition: triangles – $\text{Fe}_{19}\text{Ni}_{81}$, circles – $\text{Fe}_{10}\text{Ni}_{90}$.

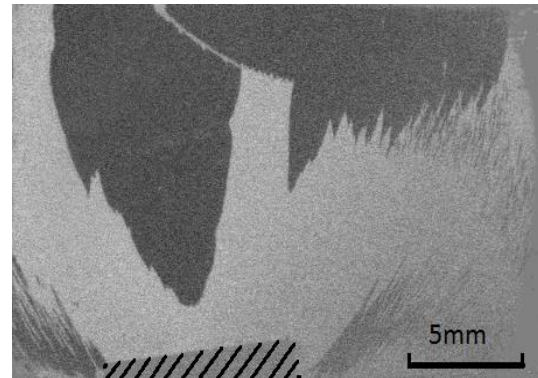


Figure 4. Domain structure in $\text{Fe}_{10}\text{Ni}_{90}$ sample (22×14 mm) in the process of quasistatic magnetization reversal along easy magnetization axis. Hatching marked the “shadow” of the holder.

On each of the six micro areas, measurements were made of hysteresis loops by which the direction of the easy magnetization axis α , coercive force H_c and anisotropy field H_a were determined. These data are shown in table 1. The angle α was measured from the direction which is perpendicular to the deposition field.

Table 1. Data of magneto-optical measurements in micro areas

micro area number	α (deg)	H_c (Oe)	H_a (Oe)
1	-15	2.7	4.4
2	+10	2.8	6.6
3	+14	2.9	3.9
4	-38	2.8	6.8
5	+13	2.9	6.8
6	+45	2.8	5.2

As can be seen, the direction of the easy magnetization axis and the magnitude of the anisotropy field have a significant variation in the sample area. This is confirmed by the form of the domain structure in the sample (22×14 mm), observed in macro mode (see figure 4).

Assuming that the directions of the domain boundaries approximately coincide with the direction of the easy magnetization axes, one can see that the micro measurement data correlates with the directions of the easy magnetization axes shown by the domain structure form. Such a significant variation in the direction of the easy magnetization axis certainly requires an explanation.

Note that the direction of the axis of magnetization is determined by the competition of two mechanisms that generate mutually perpendicular directions of the axis.

The first mechanism is associated with the form anisotropy of crystallites and crystallite chains. The second mechanism is associated with mechanical stresses and magnetostriction.

It seems to us most likely that the cause of this effect is non-uniform mechanical stresses generated by the uneven temperature field of the substrate. In figure 4 one can see how the directions of the easy magnetization axes diverge radially from the holder's “shadow”.

It is also possible that the holder has a distorting effect on the deposition field. The fact is that during multiple depositions, a certain amount of ferromagnetic material may be deposited on the holder, which is magnetized in the deposition field. This question requires additional research.

5. Conclusions

We believe that the proposed model can be used as a tool in further fundamental research, bearing in mind the establishment of mechanisms for the formation of magnetic anisotropy.

Understanding the anisotropy formation mechanisms associated with magnetostriction and different thermal expansion coefficients of conjugate materials is also important from a practical point of view. For example, in the development and manufacture of magnetoresistive sensors in the framework of planar technology [1] or glass-coated ferromagnetic microwires [6]. This effect can be used to control anisotropy in magnetoelectronic elements.

The results were obtained in the Laboratory of Magnetic Sensorics of Ural Federal University in the performance of the state task of the Ministry of Education and Science of Russia, project 3.6121.2017/8.9.

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